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RESEARCH PAPER

ASSESSING THE QUALITY OF DATA FROM CONTINUOUSLY OPERATING REFERENCE STATIONS IN GHANA

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ABSTRACT

Since 2019, Ghana has witnessed the establishment of new Continuously Operating Reference Stations (CORS) sites by the Licensed Surveyors Association of Ghana (LISAG) to augment the five existing CORS which were established in 2007 by Government of Ghana. However, limited study has been carried out on quality of data from these CORS stations regarding the standards set out by the International GNSS service (IGS) Site Guidelines, 2015. This study presents preliminary reports on pseudorange multipath effects, cycle slips and data completeness in CORS data using Translate, Edit and Quality Check (TEQC) software. The study used data observed simultaneously from receivers mounted at different sites with interstation distances of up to 200km. The results showed noticeable variations in the quality parameters measured at the CORS stations. The Root Mean Square (RMS) values of pseudorange multipath on L1 signal (MP1) and L2 signal (MP2) at the test stations were within the threshold of 0.5m contained in IGS Site Guidelines of 2015. All observed CORS data were available between 99.07% and 100% completeness which is well above the 95% thresholds set by IGS. The CORS stations recorded cycle slip counts fluctuating between 4 and 16. The study concluded that multipath effects in Ghana are location dependent with higher variability. Quality reports on CORS data provide useful information to CORS operators and users for decision making.

Keywords: GNSS, CORS, Multipath, Cycle Slip, Data Completeness

INTRODUCTION

Presently the CORS network in Ghana is made of eight newly established stations owned and operated by LISAG and five existing CORS sites owned and operated by the Survey and Mapping Division (SMD) of the Lands Commission of Ghana. The CORS operated by SMD are sited in Accra, Kumasi, Takoradi, Tamale and Bolgatanga. Due to breakdown of the government CORS, this study used data from the newly established CORS operated by LISAG which are sited in Accra, Kumasi, Takoradi, Tarkwa, Koforidua, Oda, Winneba and Ho as shown in figure 1. The CORS were intended to log static data for post processing aimed at improving cadastral mapping services in Ghana (Poku- Gyamfi, 2008). In addition, the CORS observations are to be used for geodetic applications such as determination of transformation parameters and geoid model. Plans are also underway to introduce Real-Time Kinematic (RTK) and Virtual Reference Services (VRS) using the LISAG's CORS network. As newly established CORS, most stations are having initial operational challenges. Consequently, none of the stations had recorded 100% continuous data since the start of operation in 2019. It is therefore, imperative to assess the quality of these CORS data and compare with the standards set out by IGS site guidelines so that they can be incorporated into IGS CORS stations network upon recommendation.

Despite a careful selection of the CORS sites their data will always be affected by the presence of multipath effects and cycle slip counts leading to data completeness issues (Esteban *et al.,* 2012). These quality metrics vary continuously due to changes in site conditions and other natural weather occurrences (Yue *et al.,* 2016). Studies on CORS data quality in relation to multipath effects have been carried out by: (Bhuiyan and Lohan, 2012; Jau *et al.,* 2014; Xie and Petovello, 2014; Kim *et al.,* 2014; Tabibi *et al*., 2015; Vagle *et al.,* 2016). Even though the methods cited in above literature have their advantages and limitations, it has been shown that multipath error measures between 1-5m in pseudo ranges and 1-5cm in carrier phase observations (Esteban *et al.,* 2012). Cycle slip counts have also been investigated by a number of studies including (Banville *et al*., 2013; Zhang and Li, 2016; Guo *et al*., 2016). Unlike multipath effect, cycle slip count affects carrier phase observations more than pseudo ranges (Wang, 2016).

(Esteban *et al.,* 2012; Bruyninx, 2019) underscored the significance of analysing pseudo range multipath and explained how accuracy and precision of CORS data relies on pseudo range measurements such as kinematic and rapid static surveying and ionospheric monitoring. Therefore, in order to identify the effective level of cycle slip and multipath, the daily MP1-RMS and MP2-RMS variations were estimated and analysed at each CORS site in Ghana using TEQC software (Estey and Meertens, 1999). The purpose of this data quality analysis is to provide information on quality statistics to GNSS users and CORS operators for decision making. In this study, the quality metrics of 3,742 observation files between September 2019 and March 2021 are computed and analysed.

CORS Instrumentation & Distribution

The hardware for all CORS in this study consists of dual-frequency geodetic-grade GNSS receivers and antennas from Leica company. Table I presents details of receivers and antennas mounted at the various CORS sites in Ghana.

Table I CORS Distribution and Instrumentation in Ghana

Marker Name	City	Rec. Type	Ant. Type	Start Date	Latitude(N)	Longitude(W)	Operator
LISAG_SPINTEX	Accra	Leica GR50	LEIAR10	2019	5^0 38’ 1.27”	0 5^0 15’.54”	LISAG
LISAG_ADUM	Kumasi	Leica GR50	LEIAR10	2019	6^0 41’ 16.61”	1^0 37’ 30.81”	LISAG
LISAG_TAKORADI	Takoradi	Leica GRX1200 GG PRO	LEIAS10	2019	4^0 55’ 31.75”	1 46 26.63	LISAG
LISAG_TARKWA	Tarkwa	Leica GRX-1200GG PRO	LEIAS10	2019	5^0 17’ 51.72”	2^0 0’ 0.15”	LISAG
LISAG_KOFORIDUA	Koforidua	Leica GRX1200 GG PRO	LEIAS10	2019	6^0 6’ 33.37”	0^0 18’ 8.4”	LISAG
LISAG_ODA	Oda	Leica GRX1200 GG PRO	LEIAS10	2019	5^0 55’ 34.33”	0^0 59’ 11”	LISAG
LISAG_WINNEBA	Winneba	Leica GRX 1200GG PRO	LEIAS10	2019	5^0 21’ 38.18”	0^0 37’ 59.5”	LISAG
LISAG_HO	Ho	Leica GRX1200 GG PRO	LEIAS10	2020	6^0 36’ 33.31”	0^0 27’ 37.3”	LISAG

MATERIALS AND METHODS

In order to investigate the nature of multipath effects and cycle slip in Ghana, eight CORS stations were selected and mounted with the same receiver and antenna type at differing locations having interstation distances spanning between 40km and 250km. A total of 3,742 GNSS observation files measured simultaneously, were downloaded from the test CORS stations between September 2019 and March 2021. Details of the stations and their distributions are shown in Table 1 and Figure 1.

Only GPS signals were considered. TEQC software was run to compute: average daily RMS of pseudorange multipath effects on L1 signal (MP1) and L2 signal (MP2); daily cycle slip counts and percentage data completeness using CORS data stored in Receiver Independent and Exchange (RINEX) format, with a 30-second sampling rate and elevation cut off angle of 10. Results with data completeness above 95% were used for analysis. Useful statistical tables and graphs were generated as presented under the results and discussion sections. The data used in this study can be obtained upon request via info@lisagh.org or lisagh2016@gmail.com or www.lisagh.org.

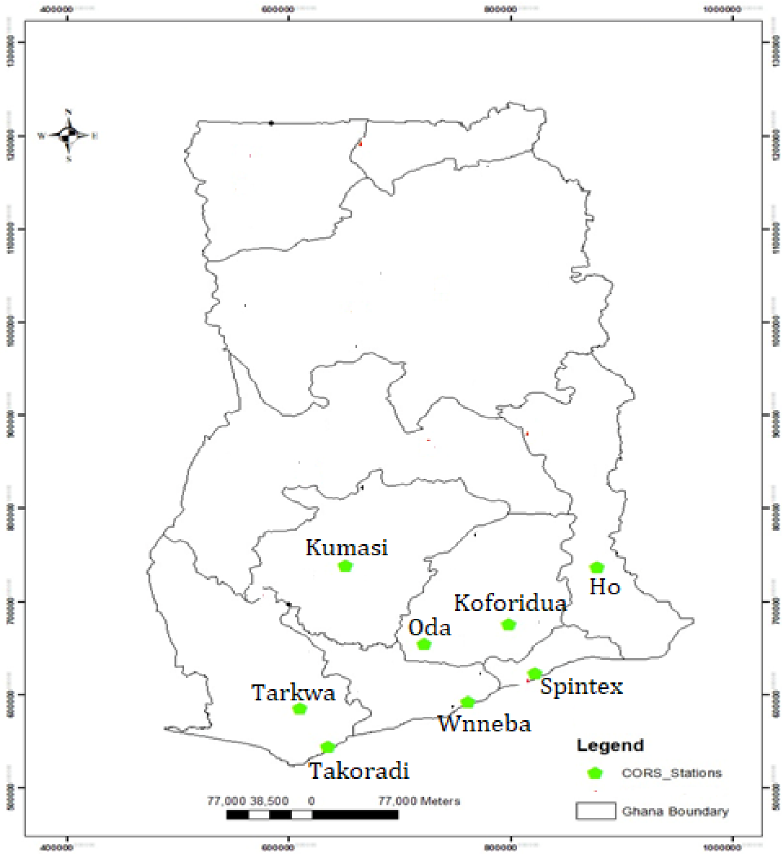


Figure 1 Map of Ghana showing locations of CORS

Pseudo range multipath estimation:

Based on (Estey and Meertens, 1999) approach, pseudo range multipath measurements on L1(MP1) and L2 signal (MP2) for a satellite (k) and a receiver *(i)* are given by:

$$P_{L1} = R + c(t^k - t_i) + I_{L1} + T + MP_{P1} \quad (1)$$

$$P_{L2} = R + c(t^k - t_i) + I_{L2} + T + MP_{P2} \quad (2)$$

The pseudorange multipath MP1 and MP2 are then expressed as the linear combination from subsequent equations as:

$$MP_1 = MP_{P1} + B_1 + M_{\varphi 1} \quad (3)$$

$$MP_2 = MP_{P2} + B_2 + M_{\varphi 2} \quad (4)$$

where: P_{Ll} and P_{L2} are the pseudo range observations (in meters), *R* is the geometric distance between the satellite and the receiver (in m), *c* is the constant speed of light (in m/s), t^K is the satellite clock (in s), t_i is the receiver clock (in s), I_{Ll} and I_{L2} are the ionospheric range errors (in m), *T* is the tropospheric range error (in m), MP_{P1} *and* MP_{P2}, are the corresponding pseudo range multipath respectively, (including the observational noise),$M_{\infty 1}$ and $M_{\infty 2}$ are phase multipath effect,B_1 and B_2 are ambiguity bias.

The full derivative can be found in (Esteban and Dorota, 2012; Estey and Meertens, 1999).

Based on the above derivations, the daily MP1- RMS and MP2-RMS variations were computed by means of equations (3) and (4).

RESULTS AND DISCUSSION

To assess the performance of each CORS site in terms of availability of daily data since the start of operation, a period of 344-days was considered. The number of days with data for each site was graphically presented in Figure 2. Starting from left to right, the stations were ranked with highest number of days with data. In Figure 2, it can be seen that LISAG_TAKORADI recorded the highest number of days with daily data since the start of operation with 318 days out of 344 days, representing 92.4%. The LISAG_SPINTEX, LISAG_ADUM and LISAG_TARKWA stations recorded 316, 316 and 297 days with daily data representing 91.9%, 91.9% and 86.3% respectively. The rest of the stations recorded less than 85% daily data availability and were not presented for further analysis. The prevalence of daily data gaps at the stations was attributed to lack of personnel attendants at the CORS stations. In addition, the LISAG_WINNEBA, LISAG_ODA, LISAG_KOFORIDUA and LISAG_HO stations were set up more recently which could still be having initial operational challenges. Therefore, in terms of data availability, the LISAG_TAKORADI station outperformed all the rest leaving the LISAG_ODA as station with least data availability. Consequently, none of the stations had 100% of day with daily data.

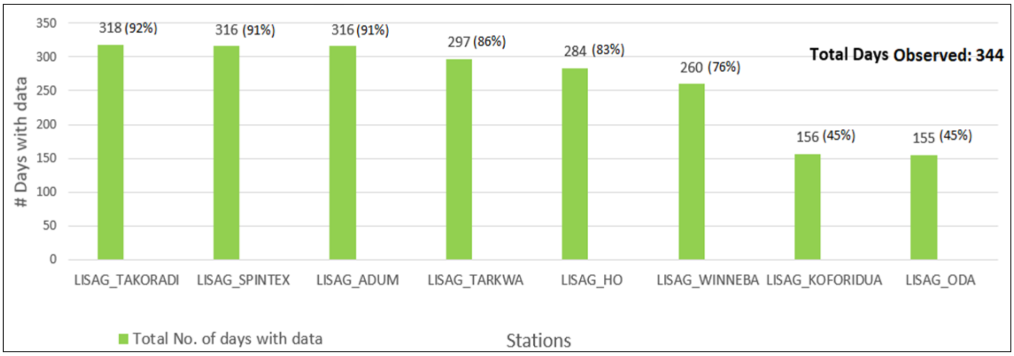


Figure 2 Data availability (in days) for CORS in Ghana

In determining which CORS station was least or most affected by multipath effects, Figure 3 was referred to. It was noticed that the LISAG_SPINTEX and LISAG_HO station were the least and most affected by multipath effects respectively. The multipath effects on L1 signal (MP1) and L2 signal (MP2) varied significantly between a minimum of 0.04m and a maximum of 0.32m across the CORS stations which all met the International GNSS services (IGS) threshold of 0.5m. This good performance of the stations in terms of multipath effects was attributed to the use of state-of-the-art receivers and mounting antennas on building tops to avoid obstructions. Even though the CORS were mounted with similar receivers (Leica GRS50) and antennas and observed data simultaneously, variability in the MP1 and MP2 persisted. This indicated that multipath effects are location dependent. The finding in this study confirmed the conclusions in (Esteban, 2012).

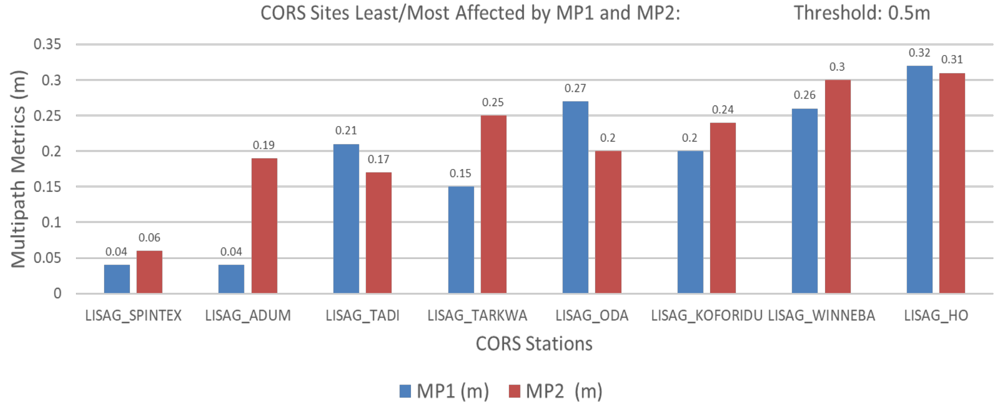


Figure 3 Multipath effects at CORS Sites in Ghana

In order to investigate the cycle slips prevalence and volume of data recorded at the CORS stations in Ghana, Figure 4 was referred to.

The minimum and maximum cycle slip counts were 4 and 16 which respectively occurred at LISAG_TAKORADI and LISAG_WINNEBA stations. The rest of the stations recorded cycle slip values between 7 and 9 counts which all below the threshold of 50 counts as set by the IGS site guidelines. According to (Chen *et al*., 2016) cycle slips are caused by factors such as solar storms, tall building obstructions, tropospheric and ionospheric effects.

In terms of data volumes, with exception of LISAG_WINNEBA which recorded 99.07%, the rest of the stations had data volumes between 99.70% and 99.94% which all met the threshold of 95% set by the IGS. Consequently, it was inferred that the CORS data were good for use in postprocessing positions for mapping applications. It was also found that the LISAG_WINNEBA station which recorded the highest cycle slip counts also recorded the lowest data volumes (see Figure 4). This means the more the cycle slips the less the data volumes.

It should be noted that data volumes are expressed in percentage as defined by (Bruyninx, 2019):

Data volume = (Actual data measured / Expected data to be measured) x 100

Cycle slips occur when the receiver loses lock with a satellite and loses count of the number of carrier phase cycles (Chen *et al*., 2016). For the analysis of cycle slips, average daily cycle slip counts recorded at each station were presented in Figure 4.

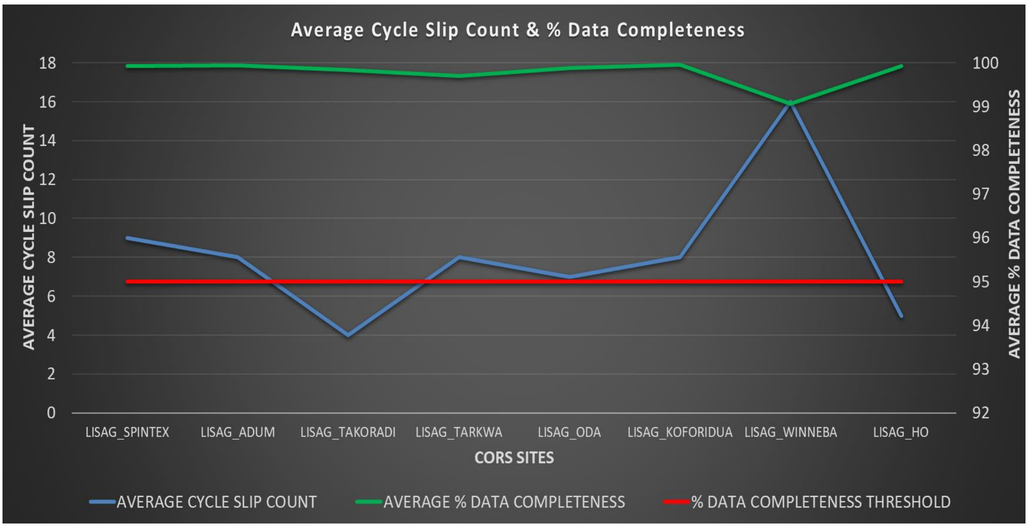


Figure 4 Average Cycle Slips Count and % Data Volumes at CORS Sites in Ghana

To further investigate satellite visibility at each station, sky plot at 10^0 using 24-hr data was generated in Figure 5. Elevations were shown radially and zenith shown at the centre. Satellite visibility is an issue which relates to all the above sources of noise in GNSS signals. As a consequence, Figure 5 presented the satellites sky plot for each CORS site used in this study.

The same number and types of satellites were visible to all the CORS sites even though interstation distances above 200km existed. All stations also showed high satellite visibility throughout the study period. This is to say that satellite visibility in Ghana is very high making it a suitable place for siting CORS for high precision applications.

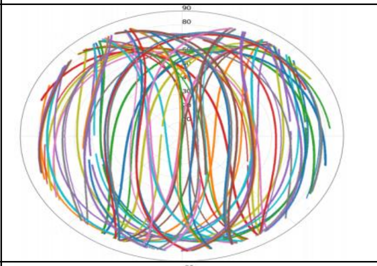
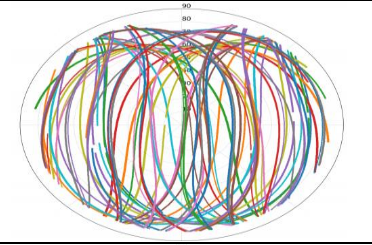
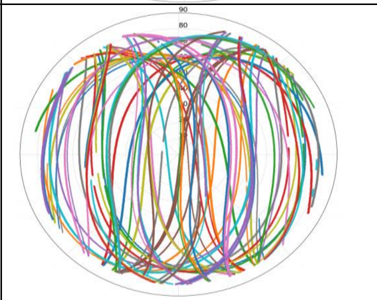
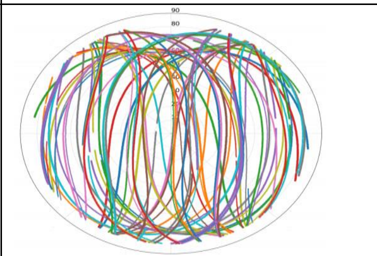
CORS SITE	SKYPLOT	SATELLITES IN VIEW AT 10^0
LISAG_SPINTEX		G01 G02 G03 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30 G31 G32 R01 R02 R03 R05 R07 R08 R09 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24
LISAG_ADUM		G01 G02 G03 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30 G31 G32 R01 R02 R03 R05 R07 R08 R09 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24
LISAG_TAKORADI		G01 G02 G03 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30 G31 G32 R01 R02 R03 R05 R07 R08 R09 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24
LISAG_TARKWA		G01 G02 G03 G05 G06 G07 G08 G09 G10 G11 G12 G13 G14 G15 G16 G17 G19 G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30 G31 G32 R01 R02 R03 R05 R07 R08 R09 R11 R12 R13 R14 R15 R16 R17 R18 R19 R20 R21 R22 R23 R24

Figure 5 Sky Plot at CORS Sites in Ghana

CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to determine whether GNSS data from the newly established CORS stations in Ghana meet the quality standards set out by IGS Guidelines of 2015. The performances of the CORS stations were assessed based on estimated daily data availability, percentage data completeness, multipath effects and number of cycle-slips per station.

Consequently, this study generated data quality reports on newly established CORS based on IGS site guidelines of 2015. All the CORS data in Ghana met the IGS site guidelines of 2015 based on the analysis in this study.

Based on the findings and conclusions in this study, it is recommended that CORS operators should provide personnel attendants at all stations to ensure continuous observations.

There is need to improve the environments of LISAG_HO and LISAG_WINNEBA sites in order to reduce their local multipath values

The study recommends for the inclusion of these CORS into IGS station network and to automate the CORS data quality reports in order to provide users some access to daily reports.

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